US006400744B1

(12) **United States Patent**
Capasso et al.

(10) **Patent No.: US 6,400,744 B1**
(45) **Date of Patent: Jun. 4, 2002**

(54) **APPARATUS COMPRISING A QUANTUM CASCADE LASER HAVING IMPROVED DISTRIBUTED FEEDBACK FOR SINGLE-MODE OPERATION**

(75) Inventors: **Federico Capasso**, Westfield; **Alfred Yi Cho**, Summit; **Sung-Nee George Chu**, Murray Hill; **Claire F. Gmachi**, New Providence, all of NJ (US); **Ruedeger Koehler**, Berlin (DE); **Deborah Lee Sivco**, Warren, NJ (US); **Alessandro Tredicucci**, Chiavari (IT)

(73) Assignee: **Lucent Technologies, Inc.**, Murray Hill, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/512,757**

(22) Filed: **Feb. 25, 2000**

(51) **Int. Cl.**[7] **H01S 5/00**; H01S 3/08
(52) **U.S. Cl.** **372/96**; 372/92; 372/45
(58) **Field of Search** 372/96, 92, 45

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,502,787 A	3/1996	Capasso et al.	385/123
5,901,168 A	4/1999	Baillargeon et al.	372/96
6,167,072 A	12/2000	Zory, Jr.	372/46

FOREIGN PATENT DOCUMENTS

EP	0877454	11/1998	H01S/3/18

OTHER PUBLICATIONS

Abstract/Zusammenfassung/Abrege, No. 00307623.9, p. 1, *An article comprising a OC–DFB laser is disclosed. . .* Jul. 17, 1901, International Search Report Abstract.

Scamarcio et al., *Long–wavelength. . .* , Semicond. Sci. Technol., vol. 13, No. 11, pp. 1333–1339 (Nov. 1998).

Namjou et al., *Sensitive absorption. . .* , Optics Lett., vol. 23, No. 3, pp. 219–221 (Feb. 1998).

Namjou, K. et al. "Sensitive absorption spectroscopy with a room–temperature distributed–feedback quantum–cascade laser," *Optics Letters*, vol. 23, No. 3, pp. 219–221 (1998).

Kosterev, A. A. et al., "Methane concentration and isotopic composition measurements with a mid–infrared quantum –cascade laser," *Optics Letters*, vol. 24, No. 3, pp. 178–181, (1999).

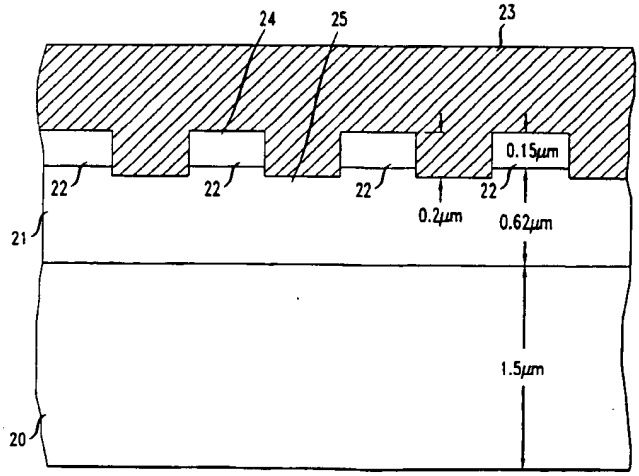
Williams, R.M. et al., "Kilohertz linewidth from frequency–stablized mid–infrared quantum cascade lasers" *Optics Letters* vol. 24, No. 24, pp. 1844–1846 (1999).

Primary Examiner—Paul Ip
Assistant Examiner—Armando Rodriguez

(57) **ABSTRACT**

An article comprising a QC-DFB laser is disclosed. In the QC-DFB laser, an overlying grating structure achieves relatively strong coupling of the guided mode to the grating, and is thus highly effective in inducing single-mode operation even under cw operating conditions. The grating structure includes grooves etched in a plasmon-enhanced confinement layer (PECL) disposed adjacent and in contact with an upper metallic electrode. The grating structure and the PECL are designed such that in the grooves, the laser mode travelling in the waveguide can couple efficiently to the surface-plasmon at the electrode interface. This results in strong modulation of the laser mode, leading to strong modulation of, inter alia, the effective refractive index.

16 Claims, 4 Drawing Sheets



US-PAT-NO: 6400744

DOCUMENT-IDENTIFIER: US 6400744 B1

TITLE: Apparatus comprising a quantum cascade laser having improved distributed feedback for single-mode operation

---------- KWIC ---------

Detailed Description Text - DETX (30):

In general, QC-DFB lasers can advantageously be used in point sensing apparatus and in remote sensing apparatus for spectral analysis and detection of many substances, particularly gaseous substances, having infrared spectral features. Numerous well-known instrumental configurations incorporating a QC-DFB laser are useful in this regard. Without limitation, such configurations include wavelength modulation, direct absorption, photoacoustic cell (PAC), and cavity ring down (CRD) configurations. Published descriptions of spectroscopic instruments incorporating QC-DFB lasers include: R. M. Williams et al., "Kilohertz linewidth from frequency-stabilized mid-**infrared** quantum cascade lasers," Optics Letters 24 (1999) 1844-1846; B. A. Paldus et al., "Photoacoustic spectroscopy using quantum-cascade lasers," Optics Letters 24 (1999) 178-180; A. A. Kosterev et al., "Methane concentration and isotopic composition measurements with a mid-**infrared quantum-cascade laser,**" Optics Letters 24 (1999) 1762-1764; and K. Namjou et al., "Sensitive absorption spectroscopy with a room-temperature distributed-feedback **quantum-cascade laser,**" Optics Letters 23 (1998) 219-221.

Other Reference Publication - OREF (5):
Kosterev, A. A. et al., "Methane concentration and isotopic composition
measurements with a mid-**infrared quantum-cascade laser,**"
Optics Letters, vol.
24, No. 3, pp. 178-181, (1999).